

Strategy Versus Evolution

Alex Pavlak

ENGINEERS—not policy makers—devised the programs that developed the atomic bomb, put men on the moon and built the Internet. So how would engineers manage the challenge of building a clean energy system?

Engineers are rational planners. They know that systems development starts with a well-defined goal. In early 2009 President Obama declared an admirably clear target: Reduce CO₂ emissions by 83 percent below 2005 levels by 2050. This is a rational strategic goal because if we are serious about controlling climate change, we will need emissions reductions on that scale.

Rational Planning

People without experience in building complex systems tend to take an evolutionary approach to planning. They start with what exists today, for example by looking for ways to reduce CO₂ emissions via direct implementation of off-the-shelf technologies. Prevailing market forces drive decision making. An evolutionary energy program can lead to efficiencies such as a switch to natural gas, the smart grid, wind power and solar installations. Some of these interventions may even make a contribution to the long-term goal, but taking a systems view, some are nearly certain to be counterproductive.

From a strategic perspective, there are few feasible paths to achieving an 83-percent reduction by 2050. Based on what we know today, the President's goal is realistic, but we must accept what a disciplined, strategic analysis tells us about how it can be reached.

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Reaching President Obama's CO₂ emissions goal for 2050 will require strategic planning

Rational planners, starting with the strategic goal, conduct scenario analyses to identify feasible choices. Based on factual scenarios, policy leaders can then create a vision that becomes the basis for a comprehensive engineering plan. This plan becomes the basis for interim goals. Various governments have been seen to leapfrog the logic by declaring interim goals such as 30-percent renewable energy by 2020. These targets are capricious and not derived from a comprehensive engineering plan. The thinking seems to be that if we are going to achieve an 83-percent reduction in 40 years, we should be able to achieve 20 percent in 10 years. A useful metaphor is the task of building an 83-story building. A strategic planner designs the whole 83-story building, then builds the first 20 stories. An evolutionary approach builds the first 20 stories and worries about how to finish the building later.

Systems, Not Components

Our political leaders have shown that they do not understand the difference between systems and components. We need a system that delivers clean energy on demand. Instead we are piling on clean components. Clean components do not necessarily mean a clean system.

A good example is the wind turbine. Wind turbines produce power at 100 percent of their rated capacity when

a storm front passes through. Without wind, no power. Even at windy locations, wind turbines on average generate only 20 percent of their full capacity. Shortfalls must be met with dispatchable (available on demand) energy, likely generated by fossil fuels. (If we had nonfossil-fuel generators that could respond quickly enough to back up wind, why have wind at all?)

Once the number of wind farms on a grid reaches about 5 percent of the average load, we encounter periods when the grid has too much power—typically in the middle of the night when load is low and the wind is high. Current law, which is the basis for much current investment in wind power, requires the grid to buy all the wind power that is produced. This forces grid operators to interrupt operations at coal plants that are designed to operate at constant power. Coal units that stop and start emit much more CO₂ and nitrogen and sulfur oxides than units that operate at constant power. Think of a Formula 1 race car in stop-and-go traffic. The excess emissions of integrating wind can wipe out the savings.

Before governments approve a wind farm, they should ask "What is the *system* impact? Will the *system* emit more or less pollution?"

Wind advocates argue that grid-scale storage (which does not exist today) can improve the average capacity. Perhaps it can, a bit. Advocates also argue that long-distance transmission increases average capacity. It does, a bit. Even if it increases average capacity by 50 percent, from 20 percent to 30 percent, 70 percent of the power must still come from backup generators.

There has been no disciplined effort to verify that wind can reduce CO₂ emissions systemwide. We do know that Denmark with 20 percent wind has not reduced its consumption of coal. A study of the Irish electrical grid

showed that CO₂ reductions due to wind may have been only 60 percent of expectations. A study from Bentek Energy, a leading analyst of natural-gas market fundamentals, suggests that wind farms in Colorado are *increasing*, not decreasing, pollution by forcing coal plants to cycle on and off and spew pollution.

Once coal plants are forced to cycle, all bets are off. A responsible engineer would not deploy wind systems without evidence that it satisfies its purpose. The purpose is not to deploy wind but to reduce CO₂ emissions by a specified amount.

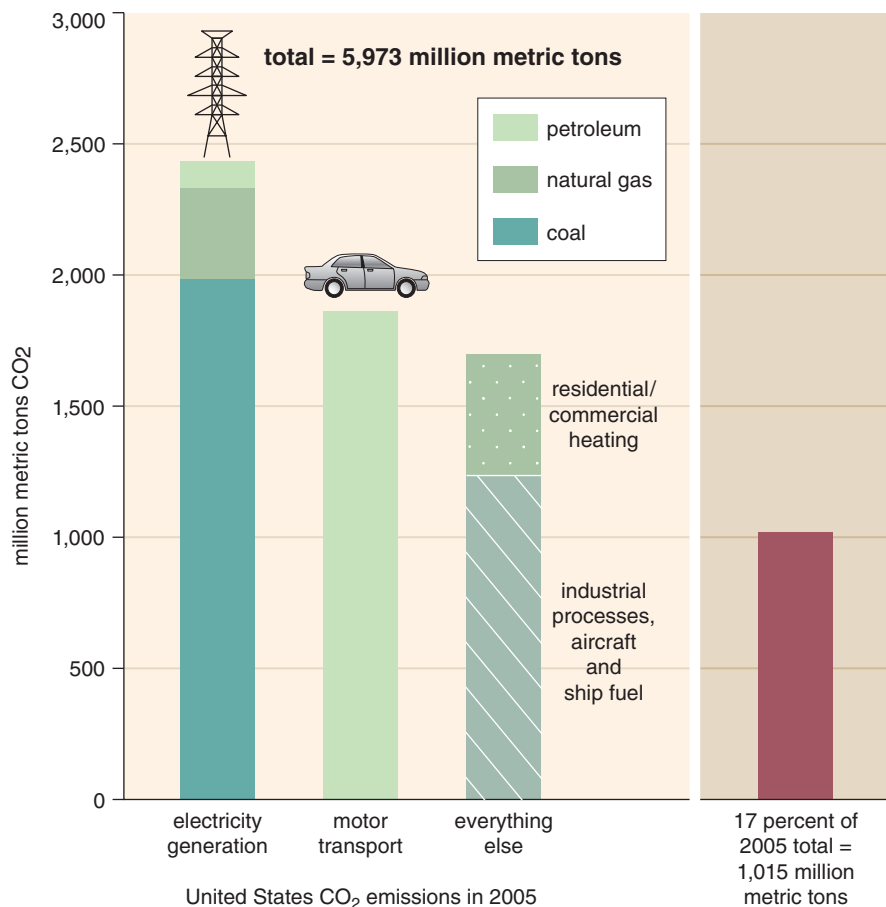
The Challenge Defined

The figure at right shows actual CO₂ emissions in the United States in 2005, the reference date for President Obama's strategic emissions goal. The first three bars indicate the amount of CO₂ emitted by electricity generation, motor transport and everything else. The red bar indicates the 2050 goal for CO₂ emissions, which is 17 percent of the 2005 total, an 83% reduction.

The fossil-fuel sources are divided among coal, natural gas and petroleum. The "everything else" bar separates residential and commercial heating from other applications. The heating contribution can be shifted to electricity fairly easily when we create a source of clean power. The rest of the "everything else" bar indicates CO₂ emissions from a mix of gas, petroleum and coal used for difficult-to-reduce, high-value applications such as industrial and chemical processes, metallurgical coal, lubricants and petroleum-based fuel for aircraft and ships.

Electricity plus motor transport accounted for 73 percent of total CO₂ emissions in 2005. Adding natural gas used by the residential and commercial sectors increases the amount to 79 percent, within 4 percent of the amount that the 2050 goal intends to eliminate. A zero-carbon power grid should allow us to substantially eliminate natural-gas emissions from spaceheating. And a variety of other technologies, such as cleaner-than-petroleum biofuels, should enable us to push emissions reduction from 79 percent to 83 percent.

The lesson of the figure is this: An 83-percent reduction in CO₂ emissions is feasible if we can create a zero-carbon electric-power grid and a zero-carbon motor vehicle fuel,



The three bars on the left show carbon-dioxide emissions from all sources in 2005; the red bar on the right shows President Obama's total emissions goal for 2050. It will be very difficult to get the 2005 category labeled "everything else" much below the 2050 goal, implying that the 2050 emissions targets for electricity generation and motor transport must be essentially zero.

with additional controls on remaining sources of emissions. Conversely, we can hardly hope to achieve an 83-percent reduction without zero-carbon electric power and a zero-carbon motor vehicle fuel.

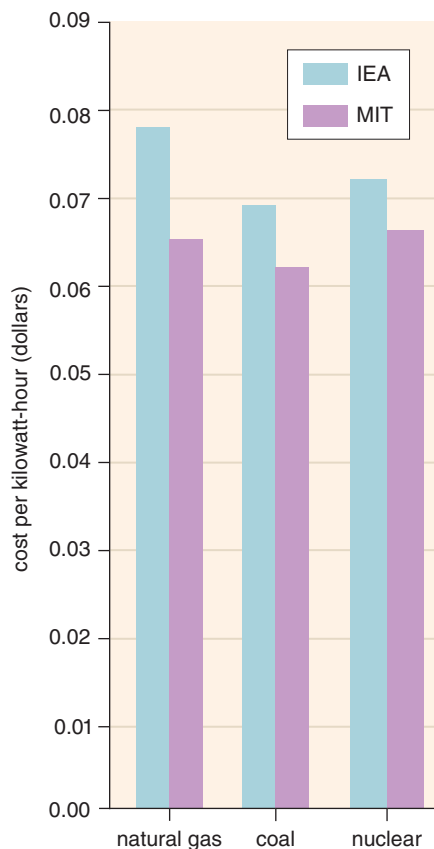
Systems from Scratch

Engineers use two approaches to create new systems. One is agile development, the other is classical planning. Agile development, sometimes called rapid prototyping, is a valuable approach for consumer products serving markets in flux. The idea is to get an early prototype to the end user quickly to discover where the real value lies. Developers then make improvements. The approach is useful when time to market is important, requirements are unclear, and the technology is changing. Agile development is the reason we have seen so many updates of the Windows operating system. The downside to agile development is that it leads to ugly, buggy and inefficient systems. Again, think Windows.

Classical planning is the best approach when requirements are explicit; reliability is important (no agile development for spacecraft); the technology is stable; and the cost of deployment is high (get long-distance power transmission right the first time). Another advantage of disciplined classical planning is education of the public along the way as scenarios are reviewed.

Agile development starts from where we are and works through a trial-and-error process similar to natural selection. Agile development is excellent when you don't know what you want until you see it. Classical planning starts from where we want to be and works backwards to develop a plan to get there from here.

The U.S. National Research Council has published a series of studies under the title *America's Energy Future*, in which committees were asked to develop a "reference scenario" that reflects a projection of technology, cost and performance. The Summary Edi-



The capital cost of nuclear power is high compared to coal and gas due to political uncertainty. Because levelized capital costs are an achievable policy goal, they were compared in economic studies from the International Energy Agency (IEA) and an MIT interdisciplinary study group. In a levelized environment, the difference in cost is hardly meaningful. (Sources: *Update of the MIT 2003 Future of Nuclear Power*. 2009. Massachusetts Institute of Technology; and *World Energy Outlook*. 2006. OECD/IEA.)

tion published in late 2009 concluded that "...There is no 'silver bullet' technology that can be deployed to overcome U.S. energy challenges. Contributions will be needed from the full array of currently available and emerging technologies." That is not a useful conclusion. We need to resist putting faith in a shotgun approach and focus on a comprehensive program designed to get us to the 2050 goal.

The danger with the evolutionary task statement is that it leads to huge investments in infrastructure, such as long-distance electricity transmission to support wind power, before it has been demonstrated that wind will have a role in the new system.

Rational planning begins with strategic scenarios, simple system models of end-state solutions. Any architectural

problem involves a set of models with enough detail to capture the structural components and produce rational estimates of cost, performance, schedule and risk. Models are based on what we know today, ignoring legacy system constraints and current policy.

Strategic scenarios are subjected to critical design reviews, the more public the better, to smoke out biases and improve objectivity. The results are then presented to policy makers for value judgments, including how much cost, performance and schedule risk is acceptable. A sketch of opening arguments for two strategic scenarios demonstrates how they compare with evolutionary thinking.

Nuclear Scenario—The development of nuclear power has been held up by unresolved waste and safety issues. Robust scenario development would require engineering solutions for both issues, rolled out in a way that explains feasible solutions to the general public during critical reviews and to policy makers during management reviews. An educated public simplifies policy. From a strategic perspective, policy makers must face the question of whether we can reach or even come close to the strategic goal without nuclear power as our primary energy source. A thorough 2050 scenario analysis would almost certainly conclude that nuclear power must have a central role.

Many feel that the job of converting to nuclear on a vast scale faces too many roadblocks. Is it true? During the past 40 years, the French built an electric-power system that is 78 percent nuclear. During the next 40 years, the U.S. could surely do the same if not better, having the example of France in view.

A persistent argument against nuclear power is the cost compared to alternatives. An important reason costs are high is the high cost of capital for nuclear construction due to political uncertainty. A widely consulted MIT interdisciplinary study, *The Future of Nuclear Power*, and the International Energy Agency have both estimated the direct cost of various generator technologies using the same cost of capital, which is an achievable policy goal. Both conclude that if the capital cost of electricity from natural gas, coal and nuclear light-water reactors were to be levelized, the cost of energy per kilowatt hour would be about the same.

Motor Vehicle Scenario—Our top-level analysis of the challenge earlier showed that both zero-carbon electric power and a zero-carbon motor vehicle fuel are essential to achieving an 83-percent reduction in CO₂ emissions. One purpose of scenario development is to identify the lines of research that are most likely to be productive. Cars propelled by hydrogen fuel cells, with hydrogen generated by zero-carbon electricity, probably nuclear, are a feasible option for the future. Building an infrastructure for fuel cells and introducing them to market will require a clear vision and considerable investment. The investment must inevitably compete with other options such as development of wind power. One will crowd the other. A determination must then be made about which direction is more likely to put us on the path to reaching the 2050 goal.

Leadership

America wants to be the global leader of the clean-energy revolution. But the world needs to believe that the leader will get the job done. The actual global leader will be a rational planner who pushes the limits of classical strategic systems engineering.

It is important to keep engineering separate from policy. Legislators should not be making engineering decisions ("We don't need a system integrator, the markets will do it"), and engineers should not make value judgments ("We can't afford that"). Mixing the roles degrades the solution.

America's energy industry is highly fragmented, with many agencies responsible for different aspects of a very mature system. America desperately needs a system integrator, an engineer in chief with the authority to enforce best engineering practices. A clear vision based on facts derived from competent scenarios can then provide the basis for global leadership. If the United States does not lead, someone else will.

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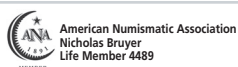
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